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AN EFFECT OF HIGH ERBIUM ON THE MECHANICAL PROPERTIES OF ALUMINIUM ALLOY

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ABSTRACT

The effects of the addition of the rare earth element, erbium (Er), on the microstructure and mechanical properties of LM 24 alloy were investigated. A microstructural characterisation was performed using an optical microscope (OM) and scanning electron microscope (SEM). When 1.0 wt % of Er was added to LM 24 alloy, the mean area decreased from 1026.16 μm^2 to 95.35 μm^2, while the aspect ratio decreased from 3.6329 to 2.322. Observations via an optical microscope showed that the unmodified alloy had a coarse plate-like structure. The addition of 1.0 wt % of Er produced the best modification effect on the Si phases, which were transformed into fine particles and short rods. The mechanical properties with various concentrations of Er were investigated by means of an ultimate tensile test and Vicker's hardness test. The results of the ultimate tensile test showed that the elongation increased with an increase in the Er content of up to 0.3 wt %, and then decreased with the addition of more Er. Furthermore, the hardness increased slightly with the addition of Er.

KEYWORDS: Aluminum, Rare Earth, Microstructure & Mechanical Properties

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Original Article

INTRODUCTION

Aluminium has a density of only 2.7 g/cm3. It typically displays excellent electrical and thermal conductivity, but specific alloys have been developed with a wide range of mechanical properties. This metal and its alloys are very economical and attractive for a wide variety of uses due to their appearance, light weight, fabricability, physical properties, mechanical properties and resistance to corrosion [1]. The predominant reasons for alloying are to increase the strength, hardness and resistance to wear of a metal [2]. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal types of aluminium alloys, namely, casting alloys and wrought alloys. Both can be subdivided into heat-treatable and non-heat-treatable categories. Various aluminium alloys have been used in industrial applications, namely, in the transport, food preparation, energy generation, packaging, architecture and electrical transmission industries. These alloys are widely used in electrical engineering for the production of construction parts such as the frames and end plates of engines, electromagnetic cases and frames, measurement devices and cable connection covers. Depending on the application, aluminium can be used to replace other materials like copper, zinc, tin plate, stainless steel, titanium, wood, paper, concrete and composites [3]. The aluminium alloy, LM 24 (also known as Al-Si8Cu3Fe), is essentially a die casting alloy, and this alloy is non-heat-treatable [4]. Furthermore, it has excellent casting characteristics. LM 24 is suitable for most engineering applications and has advantages over alloys such as LM6 when maximum mechanical properties

are required LM 24 has poor weldability and braze-ability. Aluminium alloys are widely used in lightweight or corrosion-resistant engineering structures and components [5]. Many methods are available for improving the mechanical properties of aluminium alloys, but the addition of rare elements is the most widely studied method [6]. In this study, the element was used as a modifier in order to enhance the alloy [7]. The rare earth element, erbium (Er), was added to the LM 24 aluminium alloy to observe its effects on the microstructure and mechanical properties of the alloy [8]. The mechanical properties were observed in terms of whether the addition of erbium enhanced or reduced the performance of the aluminium alloy based on the amount of the rare earth element that was added [9]. The addition of erbium significantly enhanced the tensile strength of the alloy (602 MPa) compared to that of the as-cast alloy without the addition of erbium (225 MPa) [10]. The results indicated that the rare earth element, Er, is a good modifier of the A356 aluminium alloy, and is able to improve the mechanical properties as well as the microstructure of the as-cast alloy [11]. The addition of 0.3 wt.% of Er had the best effect on the refinement of the α-Al grains and the morphology of the eutectic Si phases [12]. Moreover, it was found that the appropriate addition of Er was able to change the size and shape of the eutectic silicon, thereby refining the microstructure of the Al-Si alloy [13]. The objective of this study was to investigate the effects of erbium on the microstructure and mechanical properties of LM 24 aluminium alloy.

RESEARCH METHODOLOGY

LM 24 aluminium alloy was melted in a crucible furnace to a temperature of 750 °C, after which, different amounts of Er were added separately into the crucible. The melted alloy was manually stirred with a paddle for 30 seconds, and left for 15 minutes to ensure the dissolution of the alloying elements. Then, the melted alloys were poured into preheated steel moulds.

A microstructural evolution study was carried out on both the as-cast and modified samples to investigate the changes to the morphology of the compounds and the modification effects with the addition of Er. The samples for the microstructural study were ground and polished according to standard routines and examined with an optical microscope (Olympus BX60M) at different magnifications to identify the changes to the compounds with and without the addition of Er. An etchant of 0.5% hydrofluoric acid (HF) water solution was used to reveal the microstructure of the polished samples. The elements of the phases were characterised by a scanning electron microscope (JEOL JSM-6380) with energy dispersive spectroscopy (EDS). The tensile test was carried out at room temperature at a strain rate of 1 mm/min. The ultimate tensile strength (UTS) and elongation (EL) to failure were measured, and at the same time, a Vicker's hardness test was carried out using a Buehler Vicker's hardness tester (1900-2005-250). The results of the test load and dwell time were 0.25 N and 15 seconds, respectively. At least 5 points were measured for each specimen to reduce error, and the average value was calculated.

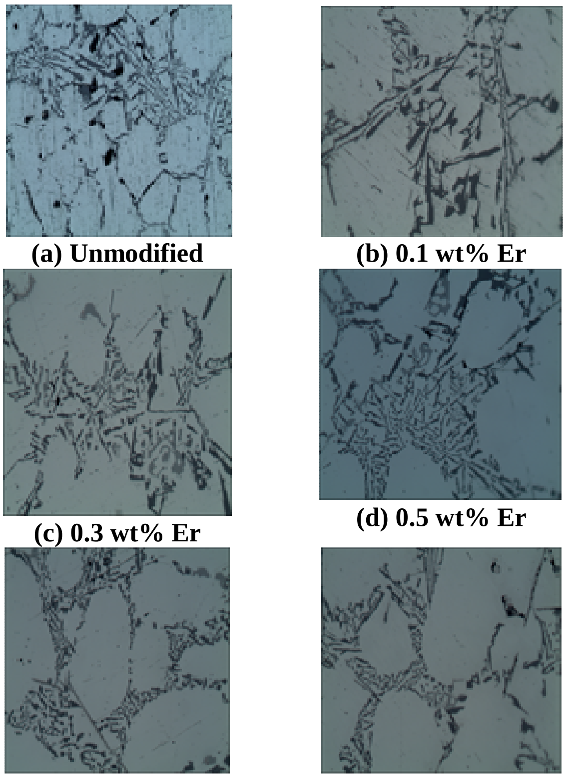
RESULTS AND DISCUSSIONS

The observations using the optical microscope were for two main analyses: (i) an analysis of the microstructure (as shown in Figure 1), and (ii) analysis of the mean area and aspect ratio (as shown in Figures 2 and 3, respectively). Figure 1 (a) shows that the unmodified LM 24 aluminium alloy had a coarse plate-like microstructure. Meanwhile, Figures 1(b), (c), (d), (e) and (f) show the results of the LM 24 alloy that had been modified with the addition 0.1 wt.%, 0.3 wt.%, 0.5 wt.%, 0.8 wt.% and 1.0 wt.% of Er. As Er has a much larger atomic weight and a slower diffusion rate than Al, the refinement effect was stronger[12]. From the figure, it can be seen that the silicon structure underwent some modifications, whereby it was changed from a coarse plate-like structure to fine particles and short rods.

The results of the microstructure test demonstrated that the addition of Er reduced the size of the silicon particles and improved the mechanical properties of the LM 24 aluminium alloy.

Figure 2 and Figure 3 show that the best concentration of Er to be added was 1.0 wt.%, as proven by the decrease in the mean area (μm^2) and aspect ratio. When 1.0 wt.% of Er was added to the LM 24 aluminium alloy, the mean area decreased from 1026.16 μm^2 to 95.35 μm^2, while the aspect ratio decreased from 3.6329 to 2.322. The addition of 1.0 wt % of Er produced the best modification on the Si phases, which were transformed into fine particles and short rods. The particle-size distribution of the silicon in the LM 24 + 1.0 wt.% Er alloy obviously differed from that of the silicon in the LM 24 alloy. The mechanisms for the refinement of primary crystals are restricted by the nucleation theory and restricted growth theory. It could be observed that Er was able to significantly refine the primary Si crystals, whereby the morphology of the crystals was transformed from a coarse star-like structure to a platelet-like structure [11].

The SEM-EDS were used to investigate the morphology and chemical composition of intermetallic. It is obvious that the addition of Er changes the shape and size of the precipitates. It can be seen in Figure 4 that the intermetallic compound was found. The elements found after performing the EDS are Al, Si, Cu and Er. It is evident that LM 24 alloy react well with the addition of Erbium. The intermetallic compound was found when 1.0 wt% of Er added into aluminium LM 24 alloy, which was Al-Si-Cu-Er , as shown in Figure 5.



(a) Unmodified **(b) 0.1 wt% Er**

(c) 0.3 wt% Er **(d) 0.5 wt% Er**

(e) 0.8 wt% Er **(f) 1.0 wt% Er**

Figure 1: Microstructure Analysis

Figure 6 and Figure 7 show the variations in the ultimate tensile strength, elongation and hardness with the Er content. In the as-cast state, the ultimate tensile strength and the elongation increased with increasing Er content. The best modification for the ultimate tensile strength and elongation percentage was achieved with 0.3 wt.% of Er. The enhancement of the mechanical properties was due to the fact that Er is a good modifier of aluminium alloys.

Therefore, it can be said that with the addition of more Er, the ultimate tensile strength and elongation decreased.

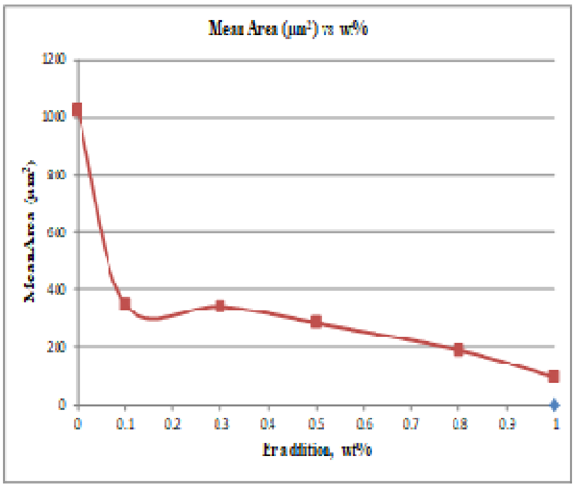


Figure 2: Mean area

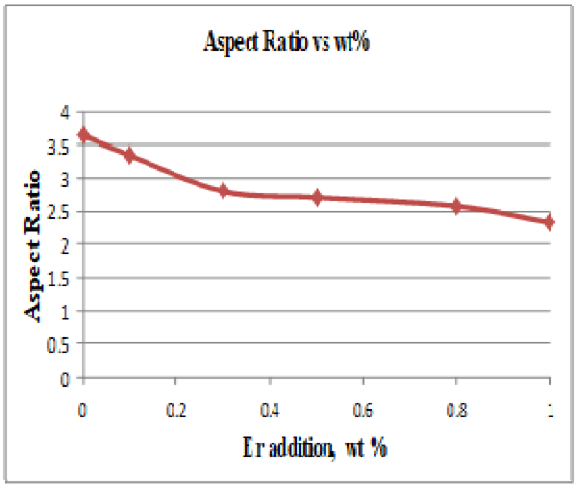


Figure 3: Aspect Ratio

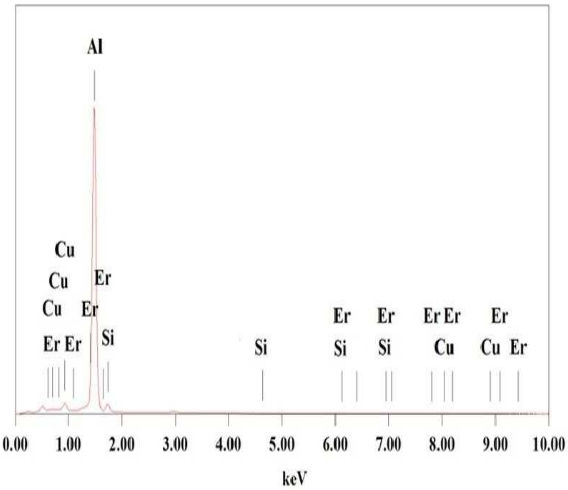


Figure 4: Electron Disperse Scanning Analysis for LM 24 Alloy with 1% Erbium

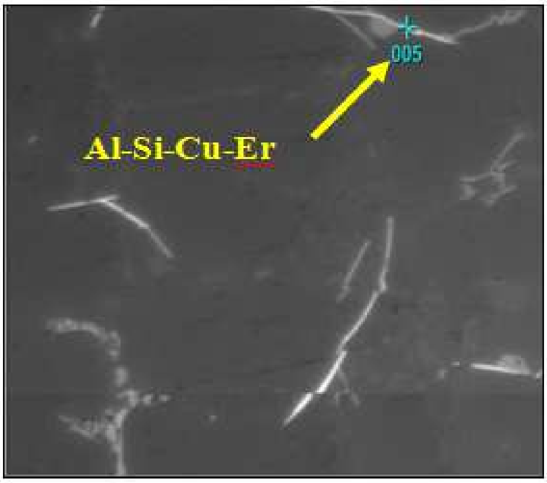


Figure 5: The SEM image of LM 24 Alloy Containing Al, Si, Cu and Er

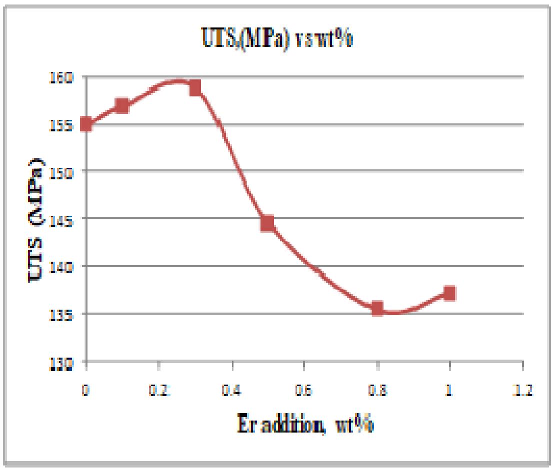


Figure 6: The Ultimate Tensile Strength for Different Percentage of Er

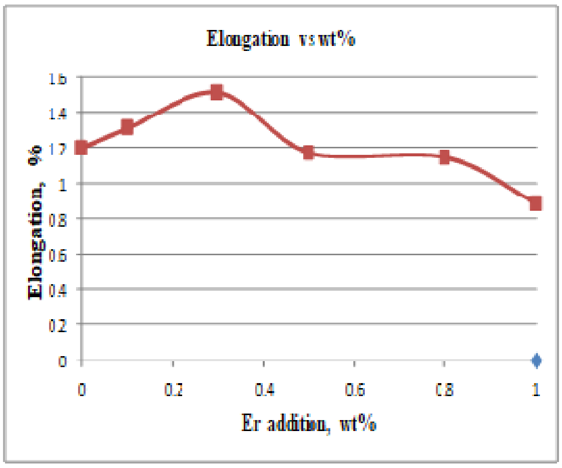


Figure 7: Elongation for Different Percentage of Erbium Addition

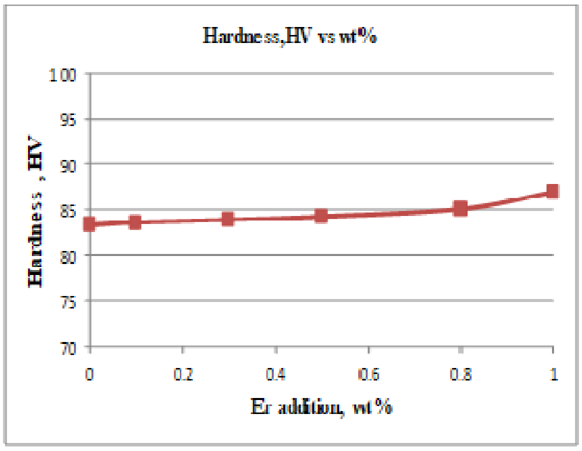


Figure 8: Hardness for Different Percentage of Erbium Addition

Figure 8 shows that the unmodified LM24 had a hardness value of 83.3 HV, which increased slightly with further additions of Er. According to the figure, a great improvement in the hardness was achieved with the addition of Er compared to the unmodified LM 24 alloy. The highest value of hardness was 86.94 HV at 1.0 wt.% of Er. The increased micro hardness of the samples modified with Er contributed to two effects, namely, the refinement and dissolution of the eutectic Si, and the precipitation of Al_3Er particles [14].

CONCLUSIONS

This study was conducted to investigate the effects of Er on the microstructure and mechanical properties of die-cast LM 24 aluminium alloy. The results showed that:

- The addition of Er had the best effect on the refinement of α-Al grains and the morphology of eutectic Si phases.
- The best modification for the ultimate tensile strength and elongation was achieved with 0.3 wt.% of Er.
- The hardness increased with the addition of Er compared to the unmodified LM 24 alloy.

ACKNOWLEDGMENT

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